OBITUARY.

The Council regret that they have to record the loss by death of the following Fellows and Associate during the past year :—

Fellows :—Prof. J. C. Adams.
Sir G. B. Airy.
Joseph Beck.
H. L. Boulton.
Dr. F. E. Brünnow.
Captain W. Chimmo.
Charles O. Dayman.
Albert Escott.
T. H. Hovenden.
Thomas Lee.
John Merrifield.
J. S. Nimkey.
N. R. Pogson.
Henry Pratt.
Benjamin Scott.
Lieut. Sidney G. Smith.
E. W. Snell.

Associate :—Eduard Schönfeld.

The obituary notice of the late Prof. J. C. Adams is deferred to the next Annual Report.

GEORGE BIDDELL AIRY was born at Alnwick on 1801 July 27. He came of a stock whose home is in Kentmere, Westmoreland, where the Airys and Gilpins live to this day; and there is a record of the marriage at Kentmere of an Airy with a Gilpin in the fourteenth century. The particular branch from which George Biddell Airy sprang had, however, not lived in Westmoreland for some generations. His father, William Airy, was a Lincolnshire man, and somewhat late in life, at the age of about 50, had married Ann Biddell, of Playford, near Ipswich. There were three other children of this marriage, one of whom died in infancy. William Airy had a minor Government appointment, which took him into different parts of the country, and it was during a stay of three years at Alnwick that George was born. He went to school at Here-

ford, and afterwards to the Colchester Grammar School, and quite early manifested great ability, although in later life he would tell quaint stories which hinted that his sympathies were not entirely with the school curriculum. It may be that he learnt things more useful to him in his subsequent career in rambling about the farm at Playford, where his uncle, Arthur Biddell, insisted on his spending not only all his holidays but some considerable portion of the year as well. But his work at school was, at any rate, so exceptional that his uncle determined to send him to Cambridge, financial troubles having put this out of the power of his parents. He matriculated at Trinity College as a sizar on 1819 November 13, and after a brilliant career as an undergraduate, in the course of which he was elected Scholar of Trinity, he graduated as Senior Wrangler in 1823. There does not seem to have been any doubt from the first as to his outdistancing all the men of his year, although from his second term he supported himself by taking pupils in addition to his own work. He was elected a Fellow of Trinity College in 1824.

While still an undergraduate, Airy had contributed a paper to the Cambridge Philosophical Society on reflecting telescopes. This society had only been in existence about three years, having been founded, according to Prof. Sedgwick, by Dr. E. D. Clarke, Professor of Mineralogy; although the "first idea" was probably due to Sedgwick himself, who, while taking a tour in the Isle of Wight early in 1819 with Mr. Henslow, "deplored the want of some place in Cambridge to which those interested in science might resort with the certainty of meeting persons of similar or kindred tastes, and where they might learn what was being done abroad." * Airy's first paper, soon to be followed by a brilliant series, was received on 1822 November 25, and is printed in the second volume of the *Transactions*. Silvered glass meant in those days apparently always glass silvered at the back: and Airy shows how the double combination of lens and mirror in a Cassegrain telescope may be used to correct both chromatic and spherical aberration. In practice the idea does not seem to have been very successful, for he candidly confesses that on trying two 4-inch Cassegrain telescopes which he had constructed, "from some cause with which he was unacquainted, the image of a star or planet is surrounded with radiations which make the telescope quite useless for practical purposes." His next paper was read on 1824 March 15, after taking his degree, and he finds that the attraction of *Saturn's* ring should produce a flattening of the planet between the pole and the equator, which did not accord with the observations of Sir John Herschel. This was almost immediately followed by a beautifully simple investigation of the achromatism of eyepieces and microscopes. Such predecessors as Euler and Boscovich had practically made no advance towards the solution of this

* *Proc. Camb. Phil. Soc.* vol. vii. p. 2.

problem, and the subject had lain untouched for forty years; and yet the method explained by Airy in a few lines is so simple that it seems incredible that it should be so long overlooked. Three years later he returned to the theory of eyepieces and discussed their spherical aberration, and again showed his great power of "going to the root of the matter," to use a colloquial phrase with which his friends are familiar. He points out that the effects of spherical aberration are three: distortion of the object, curvature of the field, and bad definition away from the centre; and specifies three corresponding problems to be solved. A table at the end of the paper of practical rules for making eyepieces is also noteworthy.

He had written other papers showing great ability; one on Astigmatism, which he discovered in one of his own eyes, is of considerable importance. He suggested a perfectly successful method of correcting it by using a concave lens, one of whose surfaces, or both, were cylindrical; and this eminently practical suggestion involved him in a great mass of correspondence. Another paper contains some very pretty geometry of roulettes, to determine the proper shape for the teeth of cog-wheels, and appears to have been the first clear exposition of the important practical principles now universally recognised; and there are others on the figure of the Earth.

In 1826 the Lucasian professorship became vacant, and Airy was elected to it on 1826 December 7, so near the end of the year that in the Cambridge Calendar for 1828 the date of his election is given as 1827, though this is corrected in all other calendars. The successors of Barrow and Newton seemed to have gradually arrived at a somewhat liberal interpretation of their duties, though there are indications of a revival of activity just before Airy's time. In the calendar for 1802 we read, "No public lectures are delivered, but the (Lucasian) Professor is at all times accessible to students of any college, by whom he is frequently consulted." In 1826, however, and for some years previously, we find that "The Lucasian Professor gives a course of Mathematical lectures gratis." On Airy's appointment this becomes "The present Professor gives a course of experimental lectures," the fame of which has lasted to the present day; although the course was not many times repeated, for on 1828 February 6, Airy was made Plumian Professor of Astronomy and Experimental Philosophy, and Director of the new Observatory. It is curious that within a few years two men should have rapidly exchanged the one of these professorships for the other; for Woodhouse was elected to the Lucasian chair in 1820 and to the Plumian in 1822. The observatory was, doubtless, the attraction to both Woodhouse and Airy, although in 1822 it was only being built. The history of its foundation is thus told in the calendars of this period:

"A very general opinion having been entertained that it would greatly add to the utility and splendour of this University,

and might essentially promote the cause of science, to erect an observatory on the most approved plan, to be furnished with the best instruments that can be procured, measures were adopted, in 1820, to carry this idea into execution. The first step taken was to procure subscriptions from members of the University, and others, and by this means upwards of 6,000*l.* was obtained; a further addition to this sum was made by a Grace of the Senate 1820 May 5, by which 5,000*l.* was granted from the public chest in aid of this design." 4,000*l.* was added by a Grace 1824 June 4, and 3,115*l.* by a Grace 1824 December 8, according to the calendar for 1830. "At the same time regulations were made by which it was resolved that the superintendence and management of the observatory should be vested in the Plumian Professor, under whose direction two assistant observers should be placed." The assistants were to be graduates of the University, at salaries of 150*l.* and 100*l.*; and their duties were to consist principally in making meridional observations of the Sun, Moon, and fixed stars. It was further resolved "That the observations so made should each year, under the care of the Observer and his assistants, be printed and published at the expense of the University, and copies of the same presented to the principal observatories of Europe, viz.: Greenwich, Oxford, Dublin, Paris, Palermo. That in addition to the capital instruments of the observatory, there should be other instruments of less size and value appropriated to the use and instruction of academical students."

The erection of the observatory was commenced in 1822 and it was completed in 1824. However, when Airy was appointed Director, in 1828, very little had been done towards the fulfilment of this excellent programme. The only instruments were a couple of good clocks and a transit by Dollond; there were no assistants, and no observations had been published. The new Director at once entered upon his duties as defined in the above programme. He made observations with the transit instrument, and reduced and published them single handed. There seems to have been some difficulty about the assistants, and he accordingly induced the Senate in 1829 February, to revoke the former regulations and place the appointments in his hands, subject to the approval of the Vice-Chancellor. The first assistant, Mr. Baldrey, was appointed in 1829 June, at a salary of 80*l.* a year. At the same time, and apparently also at Airy's suggestion, the Senate appointed a Syndicate to visit the observatory once in each term, and to make an annual report to the Senate. The beneficial results of such an arrangement have been sufficiently recognised in its general adoption throughout the world.

The history of the observatory in these early years is worth studying in some detail as illustrating Airy's power of rapid organisation. He commenced residence at the Cambridge observatory on 1828 April 15, and was away from June 28 to September 17 on a scientific mission; and yet the volume

of observations for 1828 was published early in the following year, although "every part, from the making of the observations to the revising of the proof-sheets, was done by myself" (Camb. Obs. 1828: Preface). And it must be remembered that the best methods for making and reducing transit observations were then by no means clearly comprehended, even in what might be now regarded as essentials. A few extracts from the introductions to the first few volumes of Cambridge Observations will illustrate the early difficulties and the rapidity with which they were conquered better than any comments.

"In the management of the transit instrument it will be seen that I have adopted the laborious plan of applying numerical corrections for the errors of position, instead of relying on the mechanical removal of the errors. I believe that it is no more possible to keep the instrument exactly in position than to keep the clock exactly to sidereal time; and I have thought no trouble misplaced which gave greater accuracy to the results" (Camb. Obs. 1828).

"And I would warn future observers, who may wish to determine accurately the errors of their instruments, to place no confidence in catalogues, but to rely on the simple and independent methods which were used before even approximate catalogues were formed" (Ibid.).

"About this time I found, on examining the clock errors, that the transits of Polaris agreed in showing its assumed right ascension to be too great, by nearly $1^{s}{\cdot}2$" (Ibid.).

"The multiplication of the errors by the factors corresponding to the stars observed is always performed by means of a sliding rule" (Camb. Obs. 1829).

"The mural circle was mounted in 1832 October, and was divided by Mr. Simms upon its own pier in November of the same year. On 1833 January 5, the last essential parts were received, and on the next day observations were commenced. Mr. Glaisher, the assistant by whom the greater part of the circle observations had been made, arrived on the following day. The use of a mural circle was almost wholly new both to him and to myself: I believe, however, that very few of the observations are less satisfactory on this account" (Camb. Obs. 1833).

The last extract refers to a time when Airy had succeeded in getting the instrumental equipment of the observatory tolerably complete. A $3\frac{3}{4}$-inch equatoreal by Jones had been erected in 1832 June, and was used at once, principally for observations of *Jupiter's* fourth satellite, with the view of ascertaining *Jupiter's* mass. With the arrival of the mural circle the volumes of observations assume a form closely resembling that of the modern Greenwich volumes, so far as regards meridian work, occultations, and phenomena. The comparison is closer even as regards quantity than might be expected, for, during the year 1833, Mr. Baldrey observed about 5,000 transits and Mr. Glaisher about 5,000 zenith distances.

The mural circle, of course, brought new difficulties, notably the R – D discordance. Reflection observations of stars had been instituted by Pond at Greenwich about 1821, and the discordance had already been noticed, but not explained. Airy made a vigorous effort to trace it to its origin, but was fain to be content with an empirical formula; it must be admitted, however, that what escaped his sagacity has also eluded that of his successors to the present time.

Much information about this period may be gathered from the *Report on the Progress of Astronomy during the Present Century*, drawn up by Airy for the British Association at its second meeting in 1832. He "begs the indulgence of the Society since his own connection with astronomy is of short standing;" but it is difficult to imagine that the Report could have been more complete.

It is interesting to find how nearly simultaneous was the commencement of Airy's career with that of several institutions now familiar to us. We have already mentioned the foundation of the Cambridge Philosophical Society. The Royal Astronomical Society was founded in 1820; the *Astronomische Nachrichten* commenced in 1821; the Cape Observatory was planned by the Government in 1821 and finished in 1829; and the Parramatta Observatory in 1822. We read of the first transit circle being constructed for Bessel in 1820, and of Herschel's graphical method for reducing double stars in 1832, which Airy already recognises as "really a new step in science." On the other hand, there is much in the Report which sounds strangely in our ears. To a list of "all the public observatories with which he was acquainted," numbering 41, Airy appends the remark, "I am not aware that there is any public observatory in America, though there are some able observers," and the conclusion of the Report is mainly concerned with a serious complaint against English astronomers, on two grounds: "First, that in those parts of astronomy which depend principally on the assistance of Governments or powerful bodies, requiring only method and judgment, with very little science in the persons employed, we have done much; while in those which depend exclusively on individuals, we have done little. Secondly, that our principal progress has been made in the lowest parts of astronomy; while to the higher branches of the science we have not added anything."

For the grounds of this complaint we must refer to the Report itself; but one of them supporting the second charge is that "in England an observer conceives that he has done everything when he has made an observation; he thinks that anything beyond the very first stage of reduction ought to be left to others; . . . the reduction of Bradley's observations was left to a foreigner."

Airy certainly did his best to remove this national discredit, and the keenness with which he so early felt it must be remembered in studying his life. We have seen how actively he com-

menced the complete reduction of the observations at Cambridge; and it may be mentioned here that, besides his own observations, he afterwards reduced those of Groombridge, of Catton, and of Fallows; and we shall presently refer to the laborious reduction of the lunar and planetary results of Bradley, Bliss, Maskelyne, and Pond. Meanwhile, Airy had not neglected his more strictly professorial duties, nor his own scientific work. Immediately on his election as Plumian Professor he had instituted a series of lectures on practical astronomy at the observatory; and, although only a few minor scientific papers were written in the years 1827 to 1830, which we may presume to have been fully occupied with the organisation of observatory work, the following years produced a series of memoirs of first-rate importance in the establishment of the undulatory theory of light. Among the papers in the *Camb. Phil. Trans.* is one on the theory of circular object-glasses, which may be considered fundamental. The problem seems to have been evaded as too difficult by previous mathematicians. The case of a rectilinear aperture, or a rectilinear diaphragm covering an object-glass, had been worked out, "for though sometimes tedious it is never difficult." But in the theory of the circular object-glass a more difficult integral presents itself. Airy calculated this integral numerically for the first time. He never shirked an important piece of work of this kind. Some years later (1836–1838) he wrote a fine piece of mathematics on the intensity of light in the neighbourhood of a caustic, where he obtains expressions of great generality with admirable ease; but the importance of the paper lies chiefly in the numerical calculation which he undertook to complete it, and the manuscript of which fills a large volume, though the results are printed in a compendious table of a page. But this paper was written after he came to Greenwich, and we are now reviewing his Cambridge life. There are other papers on light in the *Philosophical Magazine*, including one on the achromatic centre of interference fringes, of great importance. But his most brilliant achievement was the memoir on the inequality of long period in the motions of the Earth and *Venus* (*Phil. Trans.* 1832), for which he obtained the Gold Medal of the Royal Astronomical Society in 1832. The work occupied him some years. The possibility of the existence of the inequality was first suggested to him by a study of the errors of Delambre's Solar Tables in 1827, when he had compared them with 1,200 Greenwich observations. The complete determination of the inequality required much labour, and we can well understand the tone of triumph in which the announcement of success was made to the Royal Society: "Thus terminates one of the most laborious investigations that has yet been made in the planetary theory. . . . I believe that the paper now presented to the Royal Society contains the first specific improvement in the solar tables made in this country since the establishment of the theory of gravitation."

In the year 1835 the Astronomer Royal (Pond) resigned, and Airy was appointed his successor. A correspondence with Airy on the subject had been opened more than a year before, but Pond's resignation was delayed by circumstances then unforeseen. Meanwhile Airy's scientific services had been recognised by a pension from the Government, and it appeared doubtful whether he had anything to gain, even pecuniarily, by vacating the position which he had made famous at Cambridge for the more arduous duties of Astronomer Royal. His gratitude to the Government for the above-mentioned mark of recognition determined, however, his acceptance of Lord Auckland's offer in June 1835, and he was finally appointed Astronomer Royal on June 22. He took possession of the Royal Observatory on October 1. He did not leave Cambridge without many natural regrets, and his leave-taking was protracted by several circumstances. During the last two years he had been busily engaged in erecting the Northumberland equatoreal, presented to the Observatory by the Duke of Northumberland. It was not without some misgivings that Airy accepted the offer of the telescope, which he regarded as a possible temptation to neglect the fundamental meridian work of the Observatory. But, having accepted it, he lost no time and spared no labour to secure the efficiency of the telescope. An unfortunate accident delayed the work by many months: the flint lens was chipped in or after grinding, and M. Cauchoix had to reduce the thickness a quarter of an inch to grind out the fault, and in consequence to alter the figures of all four surfaces. It was thus not till some time after his appointment at Greenwich that Airy was enabled to report the completion of the mounting of the telescope, which he had begun and considered it his duty to finish. Again, his departure was so sorely felt by the University that his successor and others begged him to give one more set of lectures in the following spring; and though this involved an absence of five weeks from Greenwich and much extra labour, he obtained the necessary permission from the Admiralty and gave the lectures.

From the time of his appointment at Greenwich much of his life and work might be represented by a formula. The simplicity and directness of his character, which had revealed themselves in his mathematics, in the clearness of his literary style, and in the completeness of his fulfilment of any undertaking, now became apparent in the method and regularity with which he administered a large Government establishment. His early years were occupied by the orderly arrangement of the observatory as it stood, apart from the introduction of instrumental changes. He immediately instituted an annual Report to the Board of Visitors, and it is comparatively easy to gain from these Reports a general idea of the history of the Observatory. He set about arranging, binding, and cataloguing the manuscripts, and completed this work in 1841. That it was no mean labour may be gathered from the fact that "a practice was sometimes followed in Mr. Pond's time of taking books which had been only partially filled

by Dr. Maskelyne and inserting in the blank leaves calculations of a different date, and sometimes on very different subjects." He had already induced the British Association to obtain from the Government a grant for the reduction of the Planetary and Lunar Observations of Bradley, Bliss, Maskelyne, and Pond from 1750 to 1830, and this, though it must be dismissed here in a few words, was an immense labour. Ten or twelve computers were employed for many years under his supervision, forming a staff quite distinct from that of the Observatory. The work well deserved the award of the gold medal of the Royal Astronomical Society, which Airy received in 1847 for the Planetary Reductions, and the testimonial (equivalent to the Gold Medal) in 1848 for the Lunar Reductions.

The arrangement of the library at Greenwich was one of his first cares. The importance he attached to it may well be described in his own words, in which the spirit of his Report on Astronomy in 1833 is again made manifest: "The natural tendency, in an office so much pressed with routine work, and with official business having no very close relation to science, is to be degraded into a mere bureau of clerks; and it is difficult even for the director to resist the contagion. The only antidote is to place in the power of all the means of acquaintance with the literature and the foreign systems of astronomy; to make the principal persons, at least, familiar with the speculations of ancient and the theories of modern times. It is only thus that the character of an astronomer can be made to predominate over that of a mere observer or mere calculator" (Report for 1836).

In 1838 he obtained sanction for the provision of a Muniment or Record Room, in which to preserve manuscripts. From the first he made it a rule to transact business and give instructions almost entirely in writing, and to preserve *all* manuscripts. The advantages of this system have often appeared most unexpectedly; but it must be confessed that the rapid accumulation of volumes is a great drawback to its continuous adoption.

He also greatly extended the current system of reduction and publication, for which he found his Cambridge experience valuable. In 1841 he was thus enabled to say: "Within the last few years we have advanced little, or perhaps nothing, in the extent of our observations; but we have advanced greatly in the extent of our reductions. In a word, we have made little or no progress in the character of observers, but we have advanced very much in the character of astronomers," for the full meaning of which we must again refer to the Report of 1833. Finally, he reorganised the internal arrangements with regard to the observing duties of the assistants; and his new code of regulations was so successful as to be copied elsewhere.

Order having thus been established, Airy turned his attention to the improvement of the instrumental equipment. The Observatory having been originally instituted for improvement of lunar tables, he first devised an instrument, the

altazimuth, for observing the Moon more readily in the first and last quarters, when meridian observations can only rarely be made. We find his first proposal in a special address to the Board of Visitors in 1843, and at a special meeting in November 1843 his detailed scheme was approved. The instrument was not completed till May 1847, but meanwhile the whole arrangements for observation and reduction had been completely planned, and forms for reduction printed in detail, ready for the entry of the first observation in 1847, May 16, which have not been essentially modified since. In 1847 Airy determined to substitute a transit circle for the separate meridian instruments previously in use, and soon afterwards, having dismounted the zenith tube as inefficient, the idea of a reflex zenith tube occurred to him. These instruments were constructed during the next three years, and are still in use. The quality of workmanship demanded in their construction, especially that of the transit circle, taxed the skill of the mechanicians to the utmost. The necessary accuracy in the form of the pivots was only obtained, after many attempts, by carefully rubbing down by hand all places where a delicate spirit-level showed an excrescence, and each of the pivots cost six weeks of such labour. The completion of these instruments Airy regarded as a definite change in the Observatory equipment greater than any since Bradley's time. The chronograph, constructed from designs prepared entirely by himself, was introduced in 1854. In 1855 a circular was addressed to the Board of Visitors suggesting an improvement in the equatoreals, and a $12\frac{3}{4}$-inch object-glass was obtained from Merz, of Munich, and mounted on a massive framework according to the English system. The advantages of this system for strength and steadiness Airy had already recognised in mounting the Northumberland equatoreal at Cambridge, the designs for which he closely followed in the present instance. The characteristic of all Airy's instruments is great strength and solidity, and the mounting of this equatoreal is to be used for a 28-inch refractor now being made to replace the $12\frac{3}{4}$-inch.

With the inauguration of the South-east equatoreal terminated the entire change from the old state of the Observatory. In his report for 1859 Airy remarks: "There is not now a single person employed or instrument used in the Observatory which was there in Mr. Pond's time, nor a single room in the Observatory which is used as it was used then. In every step of change, however, except this last, the ancient and traditional responsibilities of the Observatory have been most carefully considered; and in the last the substitution of a new instrument was so absolutely necessary, and the importance of tolerating no instrument except of a high class was so obvious, that no other course was open to us. I can only trust that while the use of the equatoreal within legitimate limits may enlarge the utility and the reputation of the Observatory, it may

never be permitted to interfere with that which has always been the staple and standard work here."

Meanwhile other changes had taken place in the Observatory. A single computer, engaged experimentally in 1840, was found so useful that a number were gradually added to the regular staff. But more important than this was the addition of a new department for magnetic and meteorological observations. This was suggested in 1836, but not completely carried out till 1840, when the Royal Society recommended to the Treasury the importance of making a series of observations at some place near London, in general correspondence with Captain J. Clark Ross's surveying expedition to the Antarctic Ocean, in conformity with the plan drawn up by Professor Gauss, of Göttingen, for the simultaneous observation of the movements of the magnetic needle at various selected stations in both hemispheres. At Airy's instigation Greenwich was selected as this station, and in 1841 the new department was practically complete. Although instituted for a temporary purpose, its advantages and importance were soon so manifest that it became a regular part of the establishment, and has so remained. Observations were first made every two hours by the assistants; but the system of registration by photography was introduced in 1848, and relieved the severe labour previously necessary. The results of the magnetic observations have been summarised in several memoirs in the *Philosophical Transactions*. It is curious that in two of these, read in 1863 and 1868, Airy definitely gives his opinion that there was no evidence of a ten or eleven year period in the magnetic elements, such as would be demanded by a relation between sunspots and terrestrial magnetism; and it was not until 1879 that this relation was firmly established from the very same records by Mr. Ellis.

Another new department was added by Airy to the Observatory near the end of his career, and may be described as the Physical Department. In 1873 he commenced a systematic study of the Sun's surface by means of daily photographs, taken with a Kew photoheliograph; and in the same year a spectroscope was devoted to the determination of stellar motions in the line of sight; and thus for the first time equatoreal work became a part of the regular routine at Greenwich. The equatoreals had previously been used only occasionally—for the observation of occultations, phenomena of *Jupiter's* satellites, eclipses, and comets. It is to be remarked that the new departure was still in strict conformity with the duties of the Astronomer Royal as specified in the Royal Warrant, by which he is directed "to apply himself with the most exact care and diligence to the rectifying the tables of the motions of the heavens and the places of the fixed stars. . . ."

It has been above remarked that after the establishment of order and system in the observatory, Airy's life as actual Superintendent of the observatory work was so regular and methodical

as to leave little for the chronicler to remark. But his great energy found vent in a variety of other directions. Some of the extraneous work he did was doubtless not of his own seeking; though on reviewing his life one cannot but feel that between Airy and work there was always a mutual attraction. With his memoir "On the Intensity of Light near a Caustic," written soon after his departure from Cambridge, his purely scientific career, if this term may be applied to the production of theoretical investigations, practically closed; excepting only his Bakerian lecture in 1840 on "A new Polarity in Light." But his attention was occupied by many matters of great practical importance. In 1844 he thus sums up the extraneous calls on his time and energy: "Official superintendence, as Chairman of Committee, of the restoration of the national standards (of which the immediate superintendence is intrusted to Mr. Baily and Professor Miller). Reduction of the Irish tidal observations. Printing the account of Mr. Maclear's verification and extension of La Caille's arc. Assisting the Registrar-General in regard to the Meteorological Report affixed to the weekly Sanatory Report. Aiding Mr. Struve in his proposed determination of the longitude of Pulkowa. Arranging an enterprise to determine the longitude of Valentia in Ireland, for the measure of an arc of parallel, and for the fixing of a nautical zero."

The standards of length and weight had been destroyed in the great fire at the Houses of Parliament in October 1834, and the history of their restoration is given in the "Account of the Construction of the New National Standard of Length, and of its Principal Copies," drawn up by Airy in the *Phil. Trans.*, 1857. The work included the preparation and comparison of a large number of copies of the standards for distribution to public bodies in England and to foreign Governments, thus securing the legal standards against future loss from any possible accident to the national standards. The reduction of the Irish tidal observations was a most laborious piece of work; but space forbids more than the briefest reference to many of the things Airy did. The determination of the longitude of Pulkowa may be taken as representative of a long series of longitude determinations, both by chronometers and by telegraph, which Airy superintended, including Valentia, Cambridge, Edinburgh, Glasgow, Brussels, and Paris. At the end of the same Report (for 1844) we read of the important advice given to the Canada Boundary Commission. "The most difficult part of the boundary was a straight line of nearly seventy miles in length to join two defined points. The country through which this line was to pass is described as surpassing in its difficulties the conception of any European. It consists of impervious forests, steep ravines, and dismal swamps. A survey for the line was impossible, and a tentative process would have broken the spirit of the best men. I therefore arranged a plan of operations founded on a determination of the absolute latitudes and the difference of longitudes of the two

extremities. The difference of longitudes was determined by the transfer of chronometers by the very circuitous route from one extremity to the other; and it was necessary to divide the whole arc into four parts, and to add a small part by measure and bearing. When this was finished the azimuths of the line for the two ends were computed, and marks were laid off for starting with the line from both ends. One party, after cutting more than forty-two miles through the woods, were agreeably surprised, on the brow of a hill, at seeing directly before them a gap in the woods on the next line of hill; it opened gradually, and proved to be the line of the opposite party. On continuing the lines till they passed abreast of each other, their distance was found to be 341 feet. To form an estimate of the magnitude of this error, it is to be observed that it implies an error of only a quarter of a second of time in the difference of longitudes, and that it is only one-third (or nearly so) of the error which would have been committed if the spheroidal form of the earth had been neglected."

Two of Airy's greatest practical achievements are not referred to in this list: his investigation of the disturbance of the compass in iron ships, and his work in settling the gauge of railways. The correction of the compass for the influence of the iron of a ship was not a new question. There was already in existence the "Barlow plate," professing to correct the compass, but Airy pointed out the deficiencies of this and the remedy. In fact, he undertook an entirely independent investigation of the question, which was becoming important in consequence of the introduction of large quantities of iron in the construction of ships. In the year 1838 the iron steamship "Rainbow" was placed by the General Steam Navigation Company at his disposal, and the results of the elaborate series of experiments then made are published in a paper read to the Royal Society in 1839, in which, discussing these experiments, he gave a complete solution of the problem, and drew up a set of rules showing how in a simple and practical manner the compass could be made and maintained sensibly correct. This subject brought him afterwards a considerable correspondence, and in the year 1855 he communicated a further paper to the Royal Society, in which he discussed the compass errors of a number of different ships as observed in various parts of the world. The system as originally proposed by him in 1838 has, with some small modifications, been adopted by all other countries.

The only tangible recognition of this work which he ever received was a present of a gold snuff-box from the General Steam Navigation Company, "for his discovery of an effective corrector of the influence of local attraction upon the compass in iron steamships."

The work on railway-gauges occupied a considerable time, as may be seen from the "Astronomer Royal's Journal" for 1845. A Commission was appointed to inquire into the subject, and

many visits were paid to London for the hearing of evidence of all kinds; and in January 1846 experiments were made during a series of trial-trips at very high speeds. The final report was in favour of the present standard gauge, and in the present year (1892) the last broad gauge of the Great Western Railway, which alone has ever used any but the standard gauge, will disappear. Airy's railway experiments also included an investigation of the vibration effects caused in the surrounding soil, for the determination of the limits within which trains must not approach an observatory.

Another eminently utilitarian achievement was the connection, in the year 1852, of the Observatory with the general telegraphic system of the country, and the immediate establishment of a system of hourly time signals which were automatically transmitted from a clock at the Observatory (kept adjusted to exact Greenwich time) to the then principal electric telegraph centre in London for daily distribution by telegraph to different parts of London, and throughout the country along the different railway lines for the regulation of railway and public clocks, including the daily dropping of a time-ball at Deal for giving time to shipping in the Downs. This system was the precursor of similar systems in other countries.

But it was not only in matters of practical importance such as these that his energies overflowed. Besides paying the most careful attention to current astronomical events, which yet fell outside the routine work at Greenwich (such as total solar eclipses, of which he personally observed that of 1842 at Turin, that of 1851 at Gottenburg in Norway, and that of 1860 at Hereña in Spain), he was chiefly responsible for the carrying out of two great scientific investigations—the determination of the Earth's density by pendulum experiments at the Harton Colliery in 1854, and the determination of the solar parallax by observations of the transit of *Venus* in 1874. Both these had been long contemplated. The Harton Colliery experiments were the successful issue of a third attempt after two failures. In 1826 Airy and Whewell had commenced operations in the Dolcoath mine, one of the deepest in Cornwall, where they were to observe the swinging of pendulums at the top and bottom of the mine for the comparison of the effects of gravity at these points. The accident which interrupted them is thus described: "We were raising the lower pendulum up the south shaft for the purpose of interchanging the two pendulums, when (from causes of which we are yet ignorant) the straw in which the pendulum-box was packed took fire, the lashings were burnt away, and the pendulum with some other apparatus fell to the bottom. This terminated our operations of 1826."

With three other observers the experiments were again attempted in 1828, but were suddenly stopped by the occurrence of a "fall" in the mine, and the consequent flooding of the lower station by the rise of the water. No further attempt was

made till 1854, when the introduction of chronographic registration had afforded new facilities for comparing clocks at the top and bottom of the mine. The account of the operations is given in the *Phil. Trans.* for 1856. It was found that the pendulum at the bottom of the mine would gain $2\frac{1}{4}$ seconds per day on that at the top; or, in other words, gravity was greater at the bottom of the mine than at the top by $\frac{1}{19190}$ part; and from a knowledge of the density of the stratum of the Earth's surface pierced by the mine it was concluded that the Earth's mean density was 6·6 times that of water.

It is now somewhat difficult to realise the intense anxiety with which astronomers looked forward to the pair of transits of *Venus* of the present century. It was hoped that the solar parallax would be determined with the greatest precision if only proper care were taken in the observations; for it was thought that the foreknowledge of the phenomena of the "black drop," which had been gained by a study of the observations made in 1761 and 1769, would be sufficient to enable observers to guard against this disturbing cause. Airy could certainly not be accused of delay in considering the necessary preparations and precautions. In 1857 he opened a discussion as to the best means of observing the transits of 1874 and 1882 by a paper read to the Royal Astronomical Society. In 1865 we find him already looking beyond the transit of 1874 to warn the Board of Visitors that "in reference to possible observations of the transit of *Venus* in 1882, it will be necessary in no long time to examine the coasts of the Great Southern Continent."

The British expeditions were arranged and equipped under his guidance, and his "Instructions to Observers" are a model of what such documents should be. There were to be five "Districts": Egypt, the Sandwich Islands, Rodriguez, Christchurch (New Zealand), and Kerguelen Island; and these were subdivided into several stations. The numerous observers were trained for many months, before starting for their destinations, at the Royal Observatory; and although Colonel Tupman undertook a great deal of the labour of supervision, the whole enterprise was a serious addition to the work of the Astronomer Royal. A model was constructed to show the phenomena of the transit, and the observers all practised diligently with it. That the results for the actual transit were not so satisfactory as had been hoped was in no way due to any want of care in organisation, but to the unforeseen influence of the illuminated atmosphere of *Venus*. But for this, the world would have been in no danger of forgetting that it was in great measure due to Airy's influence that the Government aided so lavishly what promised at one time to be the most important astronomical adventure of this century.

It has been remarked that Airy's purely scientific work practically terminated with his Cambridge career. His determination of the motion of the solar system in space from the average drift of 1,167 stars must be regarded rather in the light of a direct

deduction from the regular routine of observation at Greenwich than as an original investigation, although the method of procedure was sufficiently new to be still quoted as Airy's method. In 1870 we find him looking back with some regret on the change in his life and work involved in his appointment to the post of Astronomer Royal. "I have often felt," he remarks to the Board of Visitors, "the desire practically to refresh my acquaintance with what were once favourite subjects—Lunar Theory and Physical Optics. But I do not at present clearly see how I can enter upon them with that degree of freedom of thought which is necessary for success in abstruse investigations." His life had indeed been a busy and distracted one; it is hard to believe that it was not spent in the right way, for the setting of things in order, if not the work he loved best, was accepted so willingly as his life work that he was equally content in correcting solar tables, in organising a great expedition, or in labelling a number of boxes "empty." And yet he would often smilingly protest to his friends that he was intended for a life of quiet and contemplation—"he ought to have been a rural dean." It is possible that his work at Greenwich influenced him more than he himself suspected; for when the longing to resume his work of earlier days came upon him in 1870, it crystallised into the undertaking of a laborious research in lunar theory for which his failing powers ultimately proved inadequate. The fundamental conception of his numerical lunar theory was worthy of him; but the carrying out of this conception involved a close attention to a most intricate series of calculations which was not possible at the age of eighty. If it be sad to see a man die in the ripeness of his age, it is sad to read Airy's final confession that the completion of the task was beyond him; but it is the more clearly apparent that he toiled unremittingly until he could toil no more.

We have omitted to speak of many things which would be important in the lives of most men, but are trifles in that of a giant. Airy was a voluminous writer from the time when he was appointed Lucasian Professor onwards. His volume of *Mathematical Tracts*, published in early Cambridge days, and dealing with Lunar Theory, Figure of the Earth, Precession and Nutation, and Calculus of Variations, to which were added, in the second edition, Planetary Theory and the Undulatory Theory of Optics, was practically the first of Cambridge text-books in the modern sense. Other text-books were written later, notably one on Magnetism, on which he delivered a course of lectures at Cambridge in 1869. He then remarked that the novelty of the subject and the want of adequate text-books for students made lecturing difficult. Besides articles on Trigonometry and Figure of the Earth, Airy contributed a very valuable article on "Tides and Waves" to the *Encyclopædia Metropolitana*. In this he attacked Laplace's celebrated solution of the problem of the tidal oscillations of an ocean of uniform depth. This attack drew forth a defence from Sir

William Thomson, and (although Airy continued to adhere to his own view) it may be suspected that Airy's opinion would now command the assent of but few competent mathematicians. His treatment of the problems involved in the propagation of waves in rivers and estuaries, and of the other phenomena of wave motion, forms an important and original contribution to hydrodynamical science. This portion of the memoir led him on to an approximate treatment of the general tidal problem, presumably in substitution for the rejected Laplacian theory, in which the ocean is treated as consisting of a number of zonal canals. The conclusions attained are of some general interest, but are avowedly remote from the actuality on the Earth's surface. If Laplace's theory be accepted, the value of this part of the paper falls considerably. It is now generally considered that the most original and important portion of the whole is that which treats of waves; but the article on "Tides and Waves" has been for many years the leading compendium of tidal theory and practice, and, notwithstanding the advance of science since it was written, still retains much of its value.

His miscellaneous writings include essays on the locality in which Julius Cæsar first landed in Britain, and other archæological questions.

He was also an excellent public lecturer, and could expound in a charming way either the swinging of pendulums for determination of the mean density of the Earth or the manner in which the Sun's distance may be determined from transits of *Venus*; and his useful and well-known work, *Popular Lectures on Astronomy*, is the reproduction, from shorthand notes, of six lectures delivered at the Museum at Ipswich in 1848, when such lectures were almost unknown. The work is still held in much favour.

The list of Airy's honours and distinctions is a long one. He was several times President of the Royal Astronomical Society, twice received its Gold Medal, and once the equivalent of a Gold Medal. He was President of the Royal Society, and received a Copley and a Royal Medal. He was awarded the Lalande Medal of the French Academy, and was one of its eight Foreign Associates. He was made C.B. in 1871 and K.C.B. in 1872, July 30, and was shortly afterwards knighted by her Majesty the Queen at Osborne. In 1875 he received the Freedom of the City of London (which had never before been conferred for scientific distinction), "as a recognition of his indefatigable labours in Astronomy, and of his eminent services in the advancement of practical science, whereby he has so materially benefited the cause of commerce and civilisation." He was a D.C.L. of Oxford, an LL.D. of Cambridge and Edinburgh, and an Honorary Fellow of Trinity College, Cambridge. He was a Chevalier of the Order Pour le Mérite of Prussia, of the Legion of Honour of France, of the Polar Star of Sweden, of the Dannebrog of Denmark, of the Rose of Brazil, and was the recipient of many personal favours, not the least of which was a present from

the Emperor of Russia of a gold cigarette-box set with diamonds. His collection of medals and decorations numbers nearly thirty altogether.

He married, on March 30, 1830, Richarda, daughter of the Rev. Richard Smith, of Edensor, county Derby. Lady Airy died on August 13, 1875, a few days after the celebration of the bi-centenary of the foundation of the Royal Observatory. There were nine children of the marriage. The first three, all born at Cambridge, died early; the others—three sons and three daughters—are all living. One daughter is the wife of Dr. Routh, of Cambridge; the other two are unmarried, and were the constant companions of their father in his old age, more especially after his retirement from the Royal Observatory. He resigned his appointment as Astronomer Royal on August 15, 1881, in his eightieth year, and forthwith retired to the White House, on Croom's Hill, just outside the wall surrounding Greenwich Park; and here for ten years he passed a tranquil existence, varied only by regular visits to his country house at Playford, which had been customary for many years. He had a great affection for the neighbourhood in which his early days were spent, and was in return regarded with great veneration by the country-side. Writing to a local paper after his death, the present head-master of the Colchester Grammar School laments that, owing to irregularity in keeping the school register, no record remains of Airy's presence there; "and the present school building and plant are long subsequent to his time, so that no 'G. B. A.,' carved in wood or brick, remains a silent witness to his early energy." Just before his death his thoughts reverted constantly to these early days, and he would recall incidents, such as seeing Wellington's country recruits coming to have their hair cut in Colchester Castle-yard, which remind us how nearly his life spanned the nineteenth century. At the age of ninety he was in perfect physical health, and not only welcomed a large party of friends at the White House, but publicly performed the ceremony of lighting with gas the parish clock of Greenwich for the first time. An accidental fall some months afterwards, in his house at Playford, prostrated him for some time. He returned to Greenwich; but there internal complications developed which necessitated a serious surgical operation, and though for a time he appeared to rally, his strength gradually ebbed away, and he died on Saturday afternoon, January 2, 1892. He was buried in the churchyard at Playford on Thursday, January 7, with his wife and close to his three children.

H. H. T.

JOSEPH BECK was born at Stamford Hill in June 1829. He finished his school training at York, and on leaving there he was apprenticed to the well-known optical firm of Troughton and Simms. At the conclusion of his apprenticeship he became a partner in the firm of Smith and Beck, opticians, which